14303

Crystalline-matrix Breccia

898.4 grams

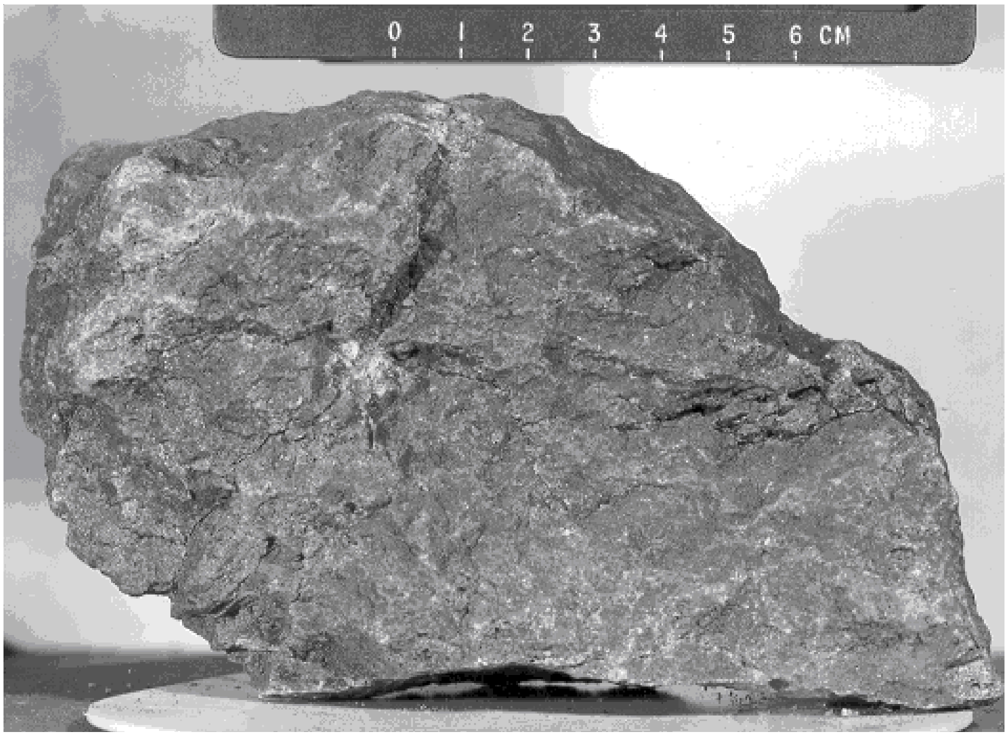


Figure 1: Bottom surface of lunar breccia 14303 (whole sample). Sample is about 12 cm.

Introduction

Lunar sample 14303 is a sample of the clast-rich, crystalline-matrix breccia that is found in abundance at the Apollo 14 site and hence probably represents the typical rock of the Fra Mauro Formation (Imbrium ejecta)(Swann et al. 1971).

Neither the location nor the surface orientation of rock 14303 could be determined from the lunar-surface photography (Swann et al. 1971). However, one side of 14303 is smoothed and rounded by micrometeorite bombardment. The other side is a large broken surface shown in figure 1. There was a large micrometeorite crater (zap pit) on the outer surface (figure 3).

14303 was returned in weigh bag #1027 which also contained fragments 14169 to 14188 (see table) as well as 14304, 14302 and 14305 – all with the same lithology. This bag also contained fines, numbered 14165-14168, including a number of 4-10 mm particles described by Kramer and Twedell (1977). The transcript shows that two large football sized rocks (14305 and 14303) were originally placed in this bag. Apparently, they each broke off a second large part (14304 and 14302 respectively) presumably also resulting in numerous smaller fragments. Additional small rock sample and some soil were also placed in the same bag. Thus the "soil" in this bag is not considered as such, because of the added broken material from the breccia samples.

Clasts in breccias 14303 and 14304 have been used as a source of small rock fragments for study – but only a few have been demonstrated as "pristine".

Petrography

The overall clastic nature of 14303 is shown in the sawn surfaces (figures 2 and 4) and in the representative thin section (figure 5). It is similar to 14305 and 14321, in that there is a "clast-in-clast" relationship indicating complex origin. Simonds et al. (1977) termed these rocks crystalline matrix breccias, because even at fine scale, there is no glass in the matrix (figure 8). They reported low porosity with about 25% clasts over 1 mm.

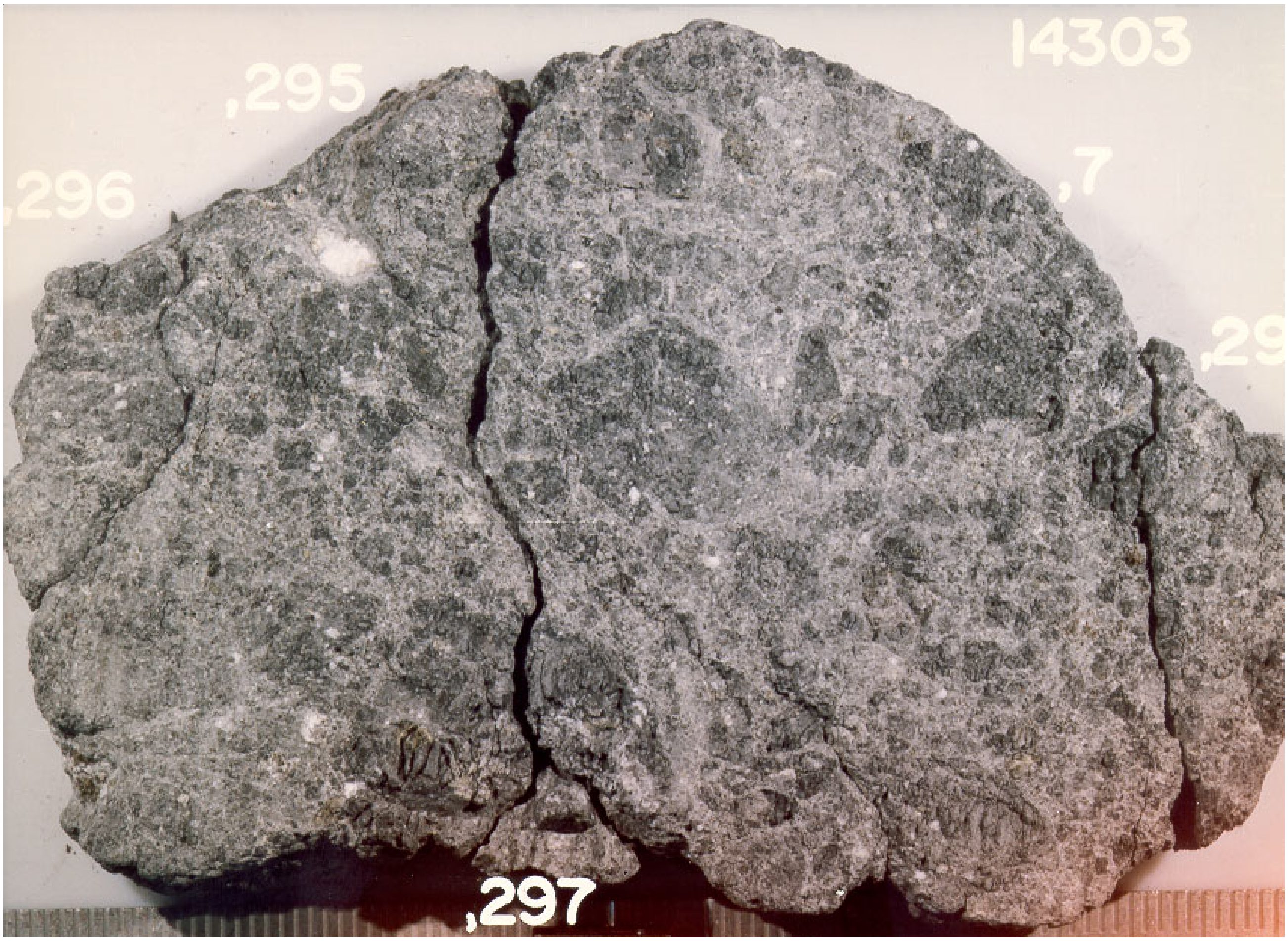


Figure 2: Photo of sawn surface of 14303,7. NASA S87-45912. Scale is in mm.

Chao et al. (1972), Wilshire and Jackson (1972) and Simonds et al. (1977) recognized that the matrix of 14303 (and similar A14 breccias) was strongly annealed (thermally metamorphized). They each offered various names to the texture of these rocks. On a very fine scale, the matrix is made up of interlocking grains of plagioclase, low-Ca pyroxene and ilmenite with occasional reaction rims around micro-xenocrysts of olivine, pyroxene or spinel. There is no glass nor devitrified glass in 14303 (nor its companion 14304). The name "crystalline-matrix-breccia" seems to serve best. Williams (1972) and Simonds et al. (1977) offer thermal models for the formation of matrix texture.

Wilshire and Jackson (1972) noted that there were more dark clasts than light ones. Weigand and Hollister (1972) studied the pyroxenes in the matrix and in a basalt clast (figure 6) and concluded that the pyroxenes were from "quickly cooled" surface rocks on the moon (not from depth). Roedder and Weiblen (1972a) noted

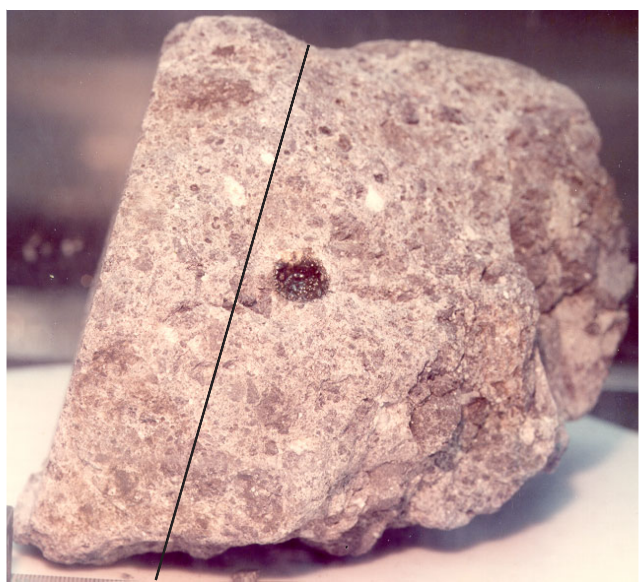


Figure 3: Photo of large micrometeorite crater "zap pit" on surface of 14303,7. NASA S77-23367. Black glass is ~6 mm across. Line is approximate location of saw cut for second slab.

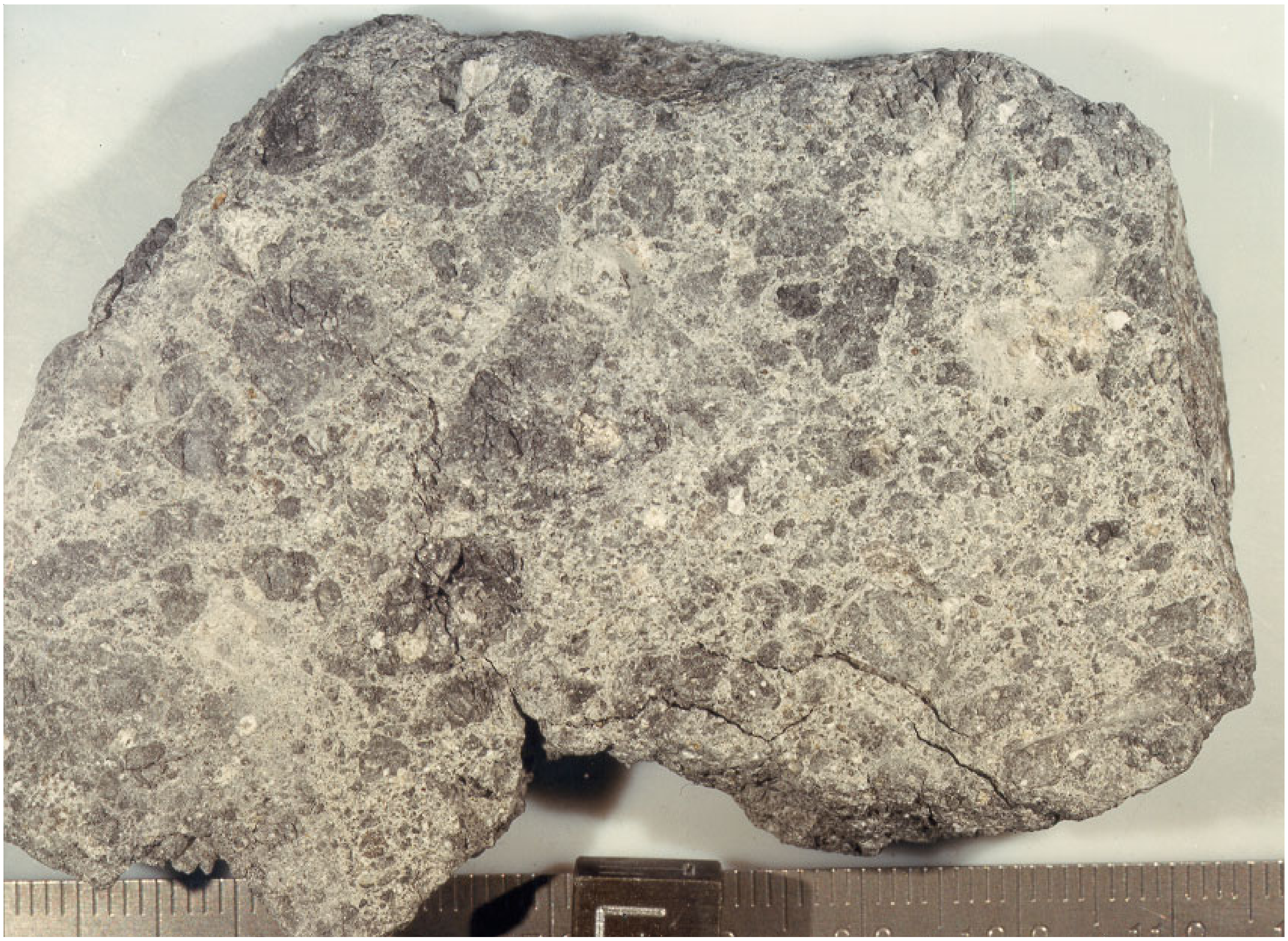


Figure 4: Photo of sawn surface of 14303,221. NASA S86-36342. Scale is in mm; cube is 1 cm..

that 14303 had excess silica in the groundmass because there was a reaction rim surrounding all olivine grains in contact with the matrix. They also speculated that the numerous "granitic" materials must indicate that there is granite in the lunar highlands! Roedder and Weiblen (1972b) studied the corona around pleonaste spinel found as individual mineral clasts in 14303, again demonstrating that the clasts have reacted with the breccia matrix.

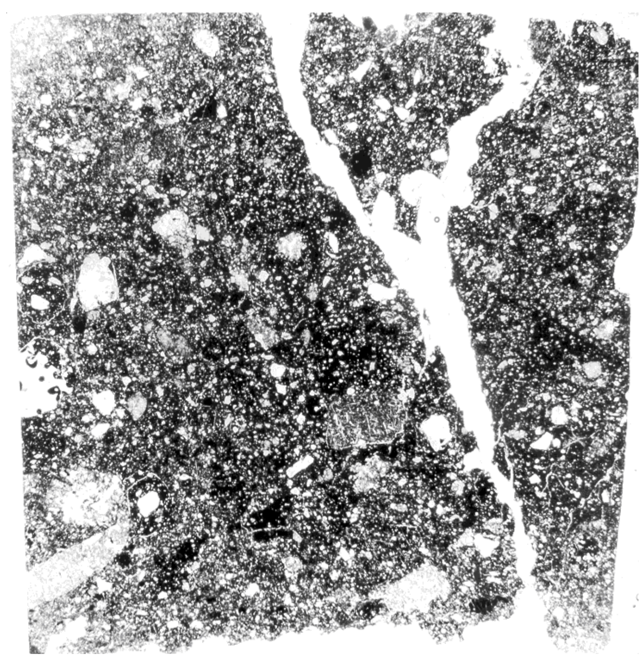


Figure 5: Thin section photomicrograph of 14303,51. NASA S71-40400. About 1 cm.

Mineralogical Mode for 14303

From Chao et al. 1972

Fine-grained noritic microbreccia	55.5%
Basalts	8.2
Anorthositic rocks	3.6
Plagioclase	7.1
Pyroxene	6.5
Olivine	0.5
Ilmenite	0.6
Spinel	0.2
Ni-Fe	0.1
Matrix	17.6

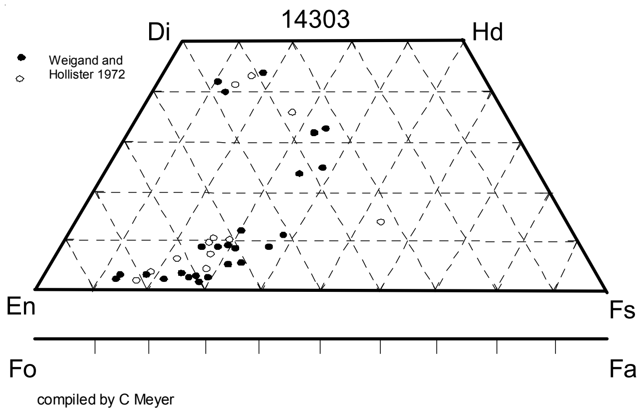


Figure 6: Composition of pyroxene from 14303 matrix and clasts.

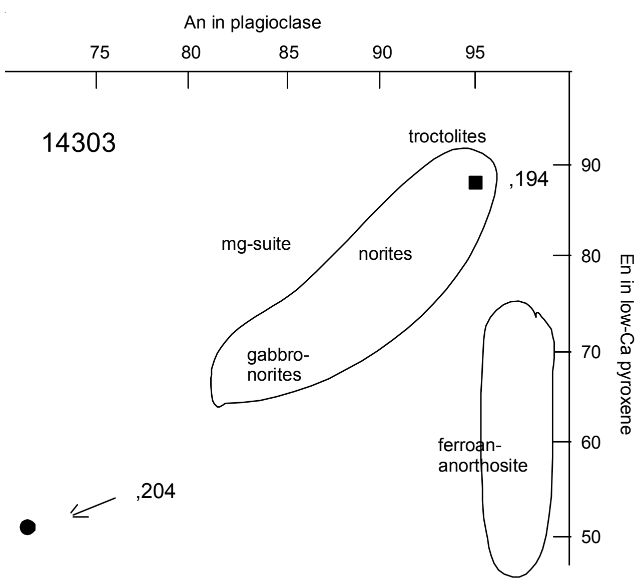


Figure 7: Mineral compositions for two "pristine" clasts from 14303 reported by Warren (1993).

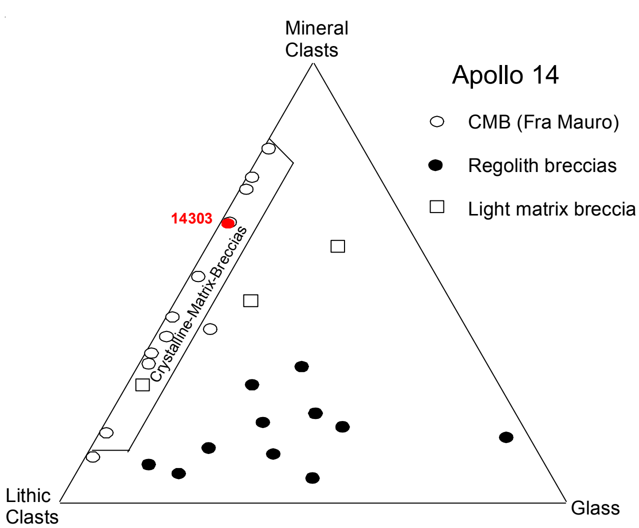


Figure 8: 14303 is a crystalline-matrix breccia (Simons et al. 1977).

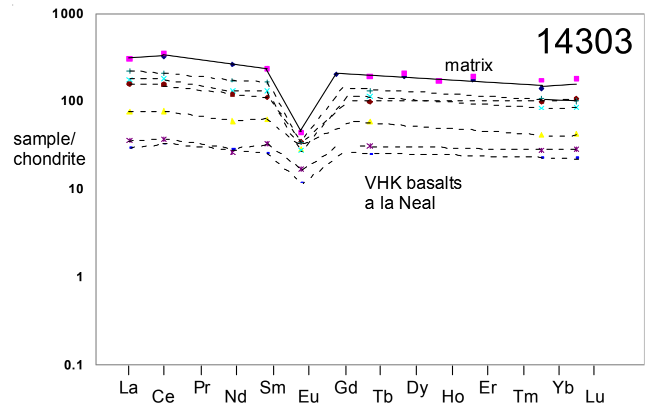


Figure 9: Normalized rare-earth-element diagram for matrix and VHK basalt clasts in 14303. The values for the matrix are from Brunfelt et al. (1972) and from 14305 sawdust (Philpotts et al. 1972). The VHK basalt data are from Neal et al. (1987, 1989).

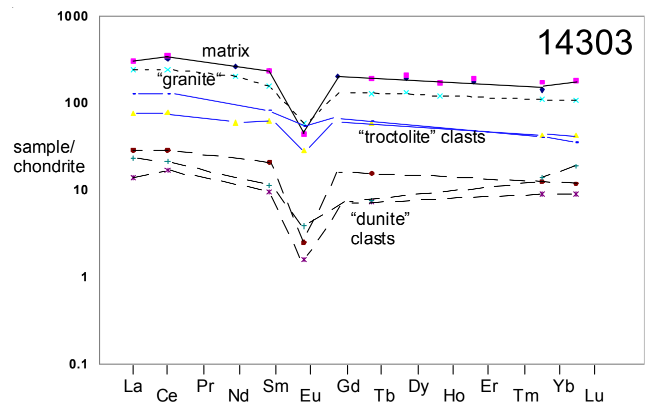


Figure 10: REE plot for 14303 matrix and various small analyzed clasts (see table 2). Note that the "granite" clast (,204) has a REE pattern similar to KREEP. Data from Warren et al., Snyder et al., and Neal et al.

Significant Clasts

Troctolite ,194 TS,200 TS,199 TS,198

Warren and Wasson (1980) described a prominent white clast in 14303 as a "troctolite" (70% feldspar $An_{94.5}$; 30% olivine $Fo_{87.5}$). It has a mass of about 2 grams, and with low siderophile element content Warren (1993) classified it as "pristine". Bersch et al. (1991) precisely determined the composition of olivine, finding low Ca content.

"Granite" ,204 ,206 TS,209

Warren et al. (1983, 1993) reported the chemical composition and mineral data of a "large" granite clast in 14303 and certified that it was "pristine". It has K,Ba-feldspar, silica, plagioclase An_{75}, olivine Fo_{42} and K-rich glass. Shih et al. (1993 and 1994) dated this

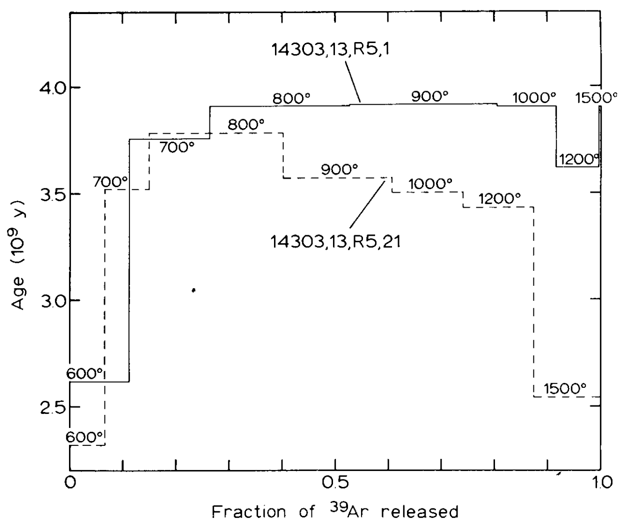


Figure 11: Ar/Ar release patterns for lunar breccia sample 14303 (Kirsten et al. 1972).

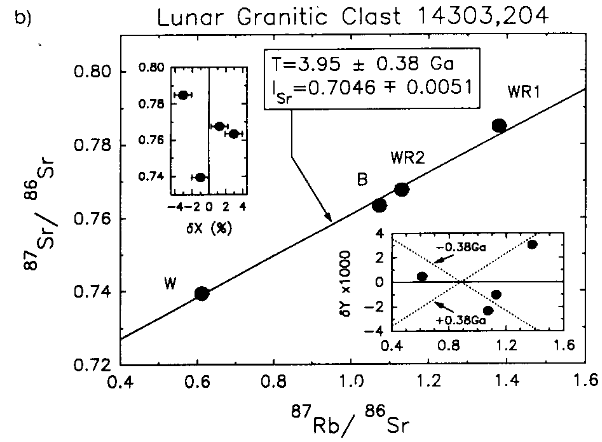


Figure 12: Rb/Sr isochron diagram for granite clast ,209 in 14303 (Shih et al. 1994).

clast at 3.95 ± 0.38 b.y. However, Meyer et al. (1996) precisely dated the zircon in this clast as 4308 ± 3 m.y. Note that it has a REE pattern like that of KREEP, not "granite" and that it is small (~170 mg) not "large", as Warren et al. (1983) stated.

HA Basalts

Neal et al. (1989a and b) reported on 22 clasts with basaltic texture, called high-alumina (HA) basalt, that they extracted from breccia sample 14303 as part of Larry Taylor's "pull apart" project. In general, the "pristinity" of these sample has not been "certified" by careful siderophile element analysis.

VHK Basalt clasts

Neal et al. (1987, 1989) reported on numerous basalt clasts with high K (figure 8). They have a wide variety of REE contents, with broad pattern similar to the matrix (were they impure and contaminated with trace amounts of matrix?).

VHK Basalt clast ,318 TS,328

Neal et al. (1989) reported a VHK basalt clast found in 14303 with a coarse-grained, ophitic texture (table 2).

Chemistry

The chemical composition of the matrix of 14303 has been determined by Rose et al. (1972) and Brunfelt et al. (1972) and is similar to that of the sawdust from 14305 (Philpotts et al. 1972)(table 1). Warren et al., Neal et al. and Snyder et al. have variously studied the composition of the clasts (figures 9 and 10).

The composition of clasts in 14303 is given in table 2. The basalt clasts are not Mare basalts, but rather a variety of high alumina basalts from lava flows that existed before the Imbrium impact. Note that the REE pattern for the "granite" clast (,204) in more like that of KREEP than of other lunar granites (figure 10).

Radiogenic age dating

Kirsten et al. (1972) determined a Ar/Ar plateau age of 3.91 b.y. for the matrix (figure 11).

Shih et al. (1993, 1994) determined the age of the "granite" clast by Rb-Sr and Ca-K method (figure 12). However, Meyer et al. (1996) precisely determined the age of a large zircon in this clast as 4.308 ± 0.004 b.y. using the SHRIMP U/Pb method.

Numerous zircons have now been dated in 14303 by Nemchin et al. (2008). Taylor et al. (2009) dated additional zircons in companion rock 14304 and determined their Hf isotopic composition.

Summary of Age Data for 14303

	Ar/Ar	Rb/Sr	Ca/K	U/Pb
Kirsten et al. 1972	3.91 ± 0.04 b.y.			
Shih et al. 1993		3.95 ± 0.38 b.y.	4.04 ± 0.64	granite clast
Meyer et al. 1996				4.308 ± 0.004 zircon
Nemchin et al. 2008				4.0 – 4.35 b.y. zircons

Table 1. Chemical composition of 14303 (matrix).

reference	Brunfelt72			Rose72		Muller75		Ehmann72		Wiik73				
weight	bulk	groundmass		,34						,41	chips			
SiO_2 %				47.49	(b)			49.42	(a)	47.43	47.9			
TiO_2	1.82	1.68	(a)	1.98	(b)					1.67	1.8	1.92	1.67	
Al_2O_3	16.57	16.12	(a)	16.05	(b)			16.44	(a)	16.8	15.6	15.5	16.4	
FeO	10.42	10.99	(a)	10.96	(b)			10.42	(a)	10.41	10.74	11.2	10.7	
MnO	0.14	0.14	(a)	0.15	(b)					0.12	0.15	0.155	0.155	(c)
MgO	10.78	10.94	(a)	10.99	(b)	9.28	(c)	10.44	(a)	10.93	10.93			
CaO			(a)	10.03	(b)	9.94	(c)			9.72	9.9	10.8	9.5	
Na_2O	0.836	0.809	(a)	0.87	(b)	0.81	(c)			0.8	0.78	0.78	0.77	
K_2O				0.46	(b)	0.9	(d)			0.7	0.52	0.47	0.6	
P_2O_5				0.56	(b)					0.62	0.6			
S %														
sum														
Sc ppm	23.2	23.9	(a)	26	(b)					24	32	26	24	(e)
V	45	47	(a)	46	(b)					53	51	46	41	(e)
Cr	1370	1420	(a)	1777	(b)					1437	1300	1410	1252	(c)
Co	30.5	34.2	(a)	28	(b)					43	22	43	34	(e)
Ni	260	320	(a)	245	(b)					380	290	360	260	(e)
Cu	75		(a)	20	(b)					75	13			
Zn	0.8-3.7		(a)							22	13			(c)
Ga	5.3		(a)	3.8	(b)									
Ge ppb														
As	0.07		(a)											
Se			(a)											
Rb	20	27	(a)	10	(b)	24.7	(d)			20	22	23	21	(a)
Sr	160		(a)	175	(b)	166	(d)				160			(e)
Y				320	(b)					210	240			(e)
Zr				940	(b)					1100	840	690	860	(e)
Nb				53	(b)									
Mo														
Ru														
Rh														
Pd ppb														
Ag ppb														
Cd ppb														
In ppb														
Sn ppb														
Sb ppb	0.03		(a)											
Te ppb														
Cs ppm	0.86	1.1	(a)			1.15	(d)			0.8	0.7	0.6	0.8	(a)
Ba	890	830	(a)	980	(b)	999	(d)			1060	1000	870	960	(a)
La	72	71	(a)	88	(b)	76	(d)			79	79	76	81	(a)
Ce	210	200	(a)							190	180	182	200	(a)
Pr														(a)
Nd										107		107	116	(a)
Sm	34.6	33.3	(a)							31	33	33	36	(a)
Eu	2.5	2.3	(a)							2.6	2	1.8	2.4	(a)
Gd										35	33	38	36	(a)
Tb	7	7	(a)											(a)
Dy	50.8	50.9	(a)							48	42	42	48	(a)
Ho	9.5		(a)											(a)
Er	30		(a)											(a)
Tm	28		(a)											(a)
Yb	28		(a)	23	(b)					23	20	19	22	(a)
Lu	4.4	4.5	(a)							3.6	3.5	3.5	3.6	(a)
Hf	25.6	25.4	(a)							26	26	24	25	(a)
Ta	3.2	3.4	(a)							3.1	4.6	4.3	5	(a)
W ppb	0.85		(a)											
Re ppb														
Os ppb														
Ir ppb														
Pt ppb														
Au ppb														
Th ppm	12.6	12.9	(a)							17	16	16	18	(a)
U ppm	3.6	3.4	(a)			4	(d)			3.9	3.8	3.5	4.1	(a)

technique: (a) INAA, (b) microchem., (c) AA, (d) NAA, (e) OES

Table 2. Chemical composition of clasts in 14303.

	,194	,204		,244	,247	,266	,275	,277		,261	,306	,308	,302		,318
reference	Warren80	Warren83		Neal87						Snyder95, Neal et al 91					Neal89
weight	troc.	granite		VHK basalt clasts						dunite	dunite	dunite	troct.		VHK basalt
SiO2 %	43.43		(a)	48.7	48.9					41	40	40	43.9		46
TiO2	0.03	0.75	(a)	1.61	1.7					0.09	0.15	0.09	0.26		1.55
Al2O3	27.02	18.5	(a)	18.2	13.4					0.47	0.63	1.97	29		13.6
FeO	3.16	5.53	(a)	9.55	13.6	16.8	9.9	12.9	(a)	16.5	14.6	11.3	2.44	(a)	15.1
MnO	0.03	0.06	(a)							0.16	0.16	0.14	0.03		0.23
MgO	11.77	3.31	(a)	8.27	9.68				(a)	40.8	43.4	45.2	7.76		10.8
CaO	14.41	8.8	(a)	12.3	10.4	10.5	11	9.9	(a)	0.45	0.5	1.1	16		11.6
Na2O	0.406	1.22	(a)	0.45	0.55	0.49	0.72	0.64	(a)	0.01	0.02	0.02	0.45	(a)	0.28
K2O	0.073	3.69	(a)	0.75	1.05	1.3	1.1	0.86	(a)	0.01	0.01	0.01	0.1		0.46
P2O5										0.14	0.07	0.05	0.06		0.04
S %															
sum															
Sc ppm	3.88	10.7	(a)	30	46	57.8	20.8	37.9	(a)	2.8	3.4	6.8	2.3	(a)	52.4
V															
Cr	261	550	(a)	1777	2595	3350	1014	2720	(a)	1680	1110	563	172	(a)	3190
Co	23.4	14.1	(a)	19.4	31.8	31.6	15.3	34.9	(a)	37.5	54.2	58.7	8.2	(a)	37.5
Ni	46	60	(a)	50	150	110	65	210	(a)	170	142	221	56	(a)	100
Cu															
Zn	0.88		(a)												
Ga		9.2	(a)												
Ge ppb	30		(a)												
As															
Se															
Rb		113	(a)	10	39	37	38	23	(a)						14
Sr		230	(a)	155	125	100	160	92	(a)						100
Y															
Zr	260	920	(a)	245	500		55	700	(a)	53	72	<40	280	(a)	110
Nb															
Mo															
Ru															
Rh															
Pd ppb															
Ag ppb															
Cd ppb															
In ppb															
Sn ppb															
Sb ppb															
Te ppb															
Cs ppm		2.2	(a)	0.2	1.41	0.89	1.75	0.99	(a)						0.54
Ba	430	2080	(a)	300	800	587	930	2720	(a)	28	28	34	451	(a)	252
La	31.7	57	(a)	18.1	41.3	8.51	37.1	52	(a)	3.18	6.79	5.47	30	(a)	7.07
Ce	77	147	(a)	47.2	109	22.7	94	127	(a)	10.5	17.3	12.9	77.2	(a)	20
Pr															
Nd	49	93	(a)	27	60	12	54	79	(a)						13
Sm	12	22.8	(a)	9.26	19.3	4.82	16.3	24.4	(a)	1.4	3.07	1.66	12.2	(a)	3.86
Eu	2.32	3.3	(a)	1.62	1.56	0.94	1.96	1.9	(a)	0.091	0.138	0.217	3.09	(a)	0.69
Gd															
Tb	2.31	4.7	(a)	2.13	4.14	1.12	3.65	4.83	(a)	0.268	0.57	0.275	2.25	(a)	0.92
Dy		33	(a)												
Ho		6.7	(a)												
Er															
Tm															
Yb	8.4	18	(a)	6.9	13.7	4.49	16.3	17.5	(a)	1.45	2.04	2.31	6.68	(a)	3.7
Lu	1.15	2.6	(a)	1.05	2.09	0.71	2.6	2.45	(a)	0.22	0.29	0.463	0.88	(a)	0.56
Hf	4.5	21	(a)	6	13	2.82	14	17.7	(a)	1	1.82	1.12	6.57	(a)	2.82
Ta	0.45	3.1	(a)	0.73	1.81	0.59	1.65	2.08	(a)	0.148	0.207	0.141	0.916	(a)	0.33
W ppb															
Re ppb	37		(a)												
Os ppb															
Ir ppb	0.13	2.8	(a)					3.9	(a)	<2.1	<1.1	<3.2	0.5	(a)	
Pt ppb															
Au ppb								2.7	(a)	<1		7.1	<1	(a)	
Th ppm	3.7	17.9	(a)	2.2	7.97	1.15	8.27	9.76	(a)	0.7	1.05	0.57	5.49	(a)	1.21
U ppm	0.55	5.6	(a)	0.65	2.37	0.55	2.4	3.35	(a)	0.28	0.25	0.11	2.1	(a)	0.44

technique: (a) INAA

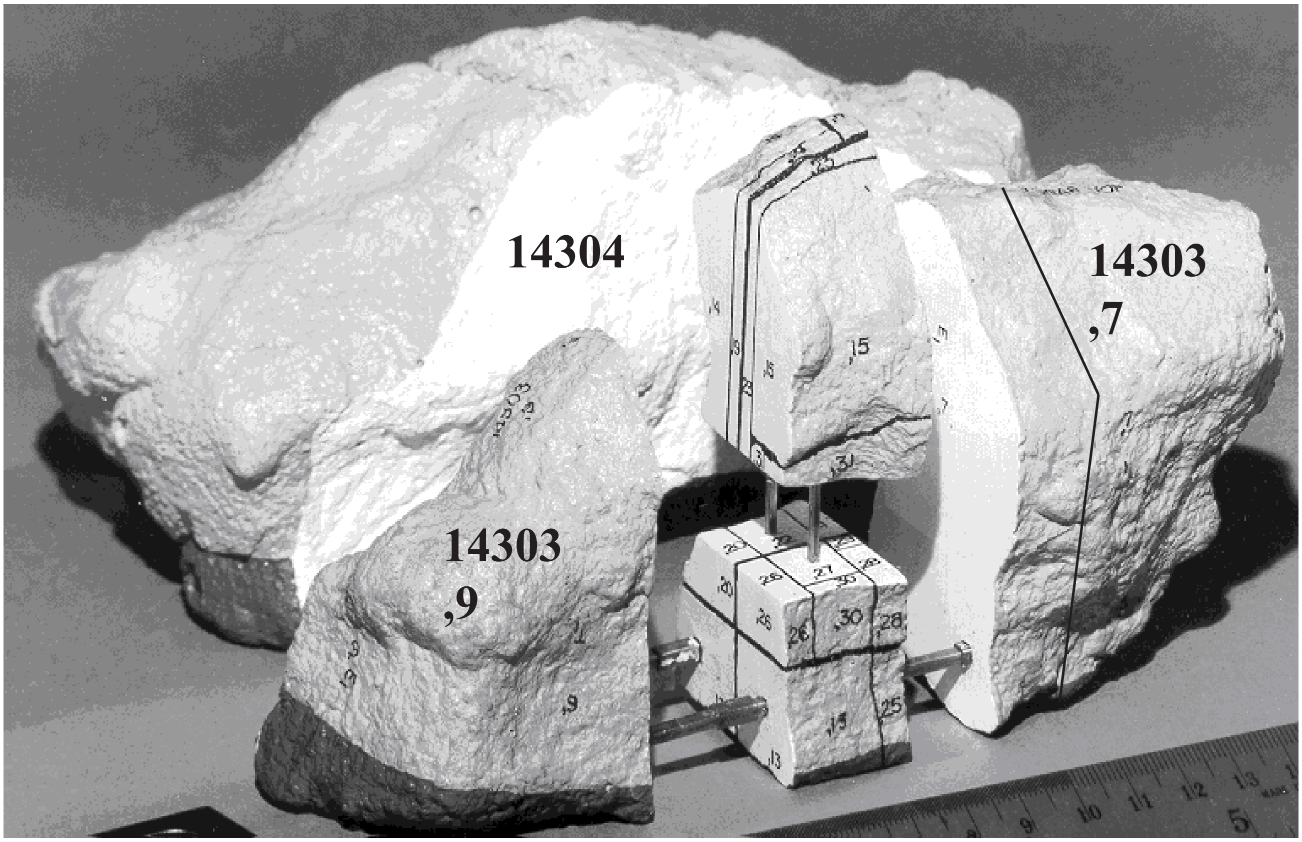


Figure 13: Photo of model of 14303-14304 pair. NASA S78-26757. Slab is 1 inch thick. 1n 1986, a second slab was cut, parrallel to the first, from 14303,7.

Table of fragments from weigh bag #1027

	Weight			
14302-14305				
14303-14304				
chips		Fines		
14169	78.55 grams	14165	109.1 g	less than 1 mm
14170	26.34	14166	20.5	1-2 mm
14171	37.79	14167	26.5	2-4 mm
14172	32.1	14168	43.9	4-10 mm
14173	19.59			
14174	11.62			
14175	7.48			
14176	4.12			
14177	2.32			
14178	2.88			
14179	3.03			
14180	4.75			
14181	2.48			
14182	2.29			
14183	1.4			
14184	1.48			
14185	1.52			
14186	1.26			
14187	1.9			
14188	1.6			

Other Studies

Kirsten et al. (1972)	rare gases
Nagata et al. (1972)	magnetism
Schwerer et al. (1972, 1976)	electrical, magnetic
Neukum et al. (1972)	micrometeorite craters
Hartung et al. (1973)	micrometeorite craters
Gibb et al. (1972)	Mossbauer
Bhandari et al. (1972)	cosmic ray induced tracks
Weeks (1972)	magnetic properties

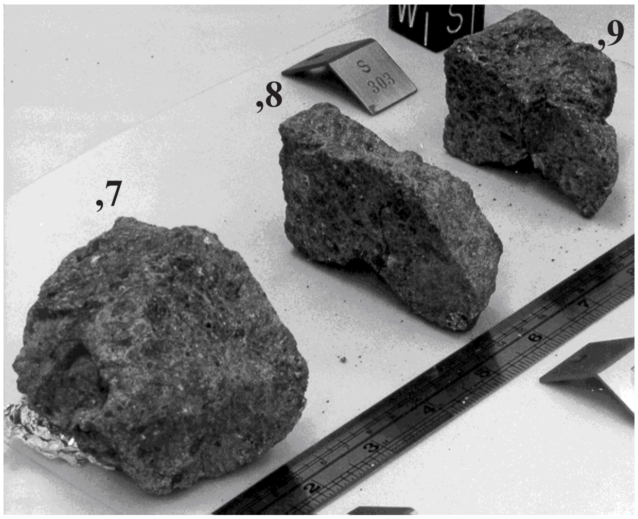
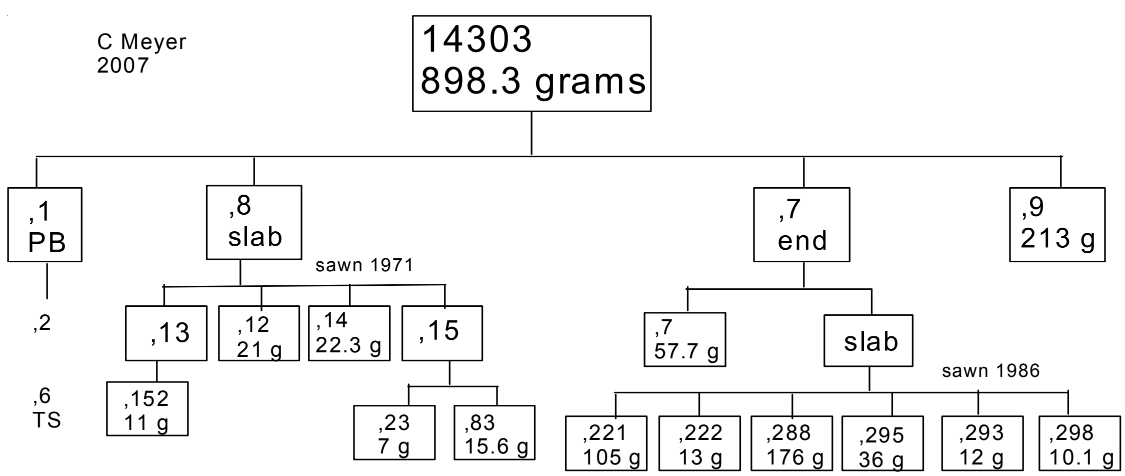
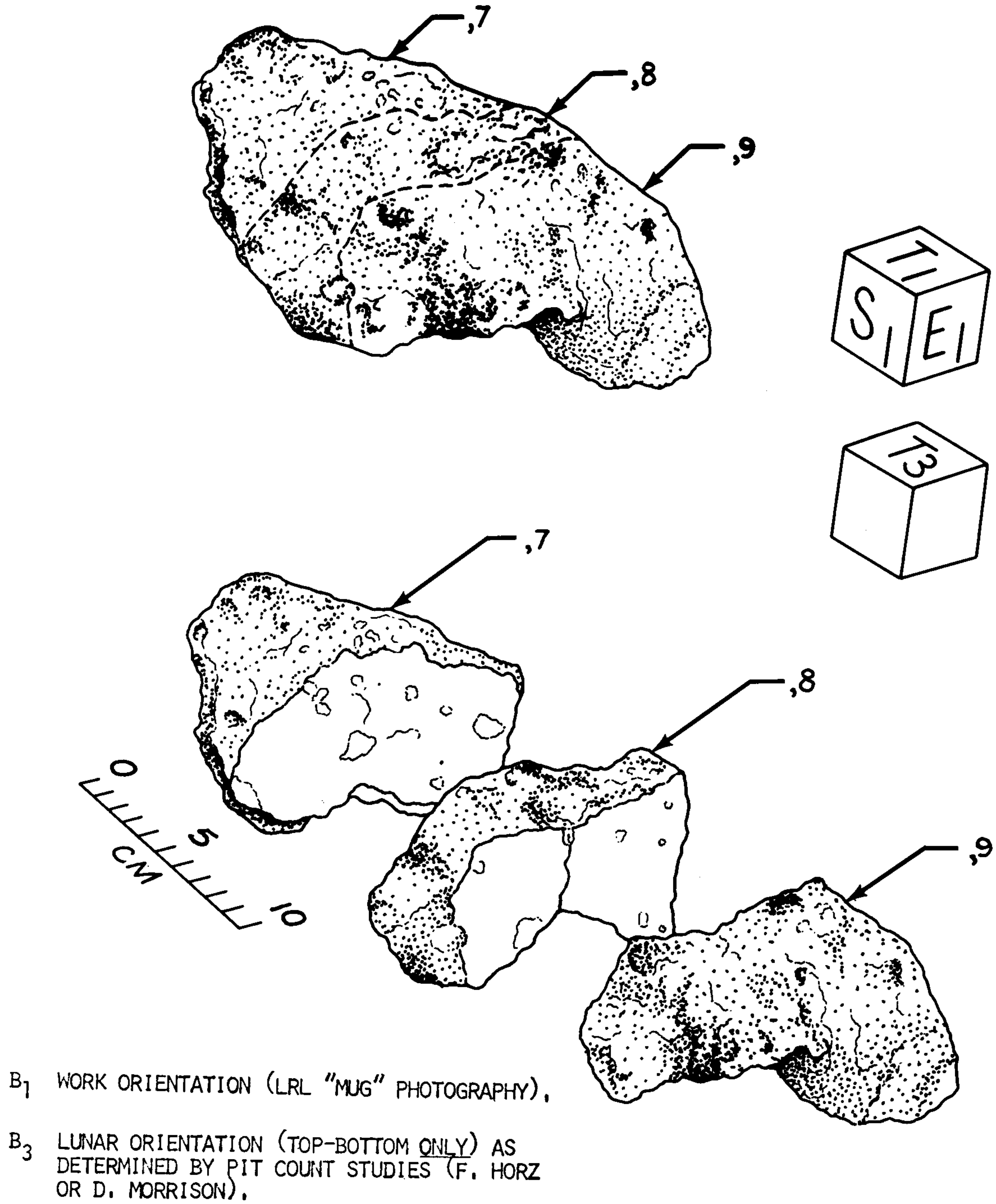


Figure 14: Processing photo of first slab (,8) cut from 14303. Cube and ruler in inches.

Figure 15: Color photo of second slab cut from 14303,7. NASA S87-3880. White clast is about 1.2 cm.

Figure 16: Second slab cut from 14303,7. Cubes are 1 inch. NASA S87-38792.



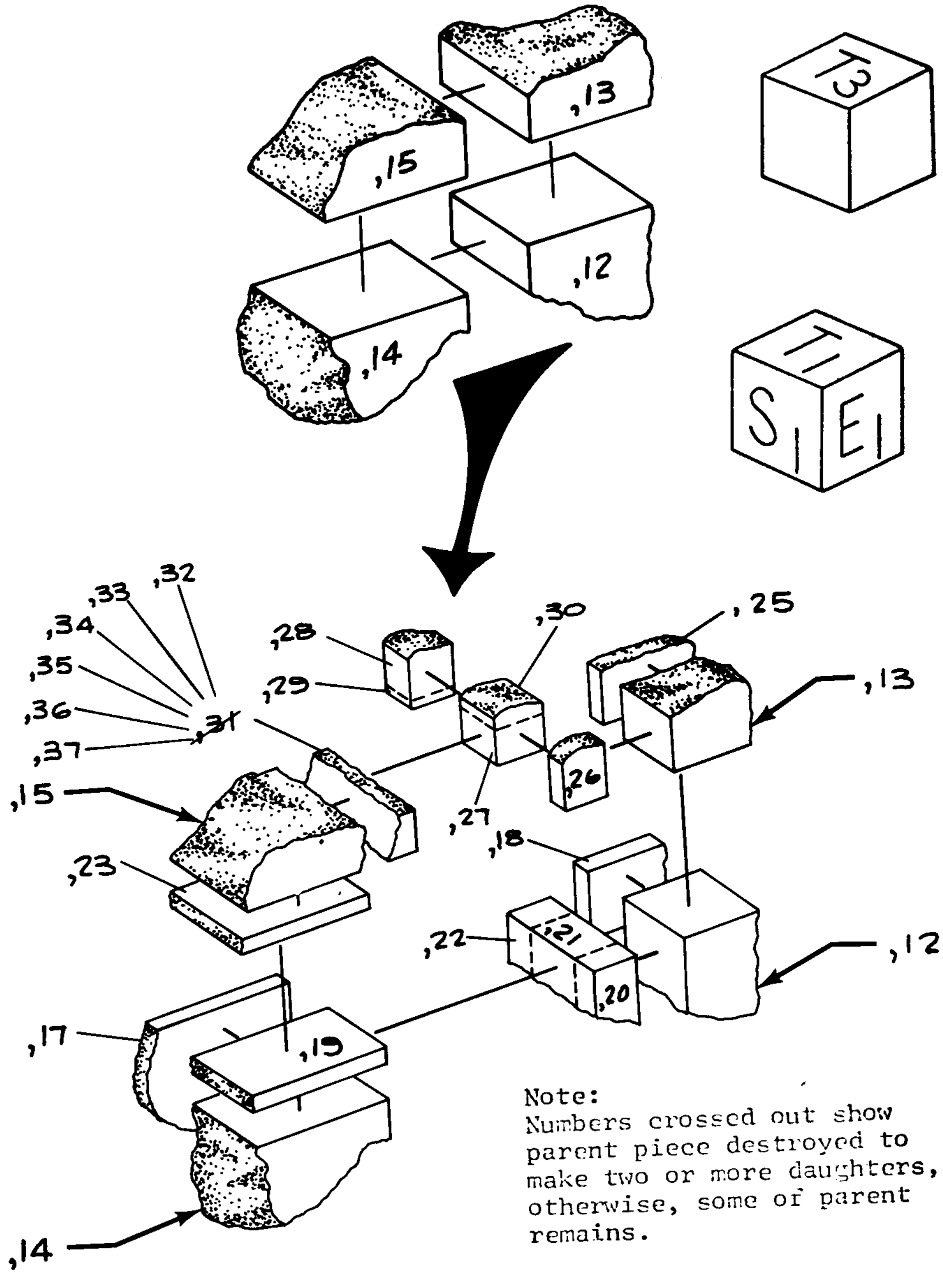


Cosmogenic isotopes and exposure ages

Kirsten et al. (1972) reported a cosmic-ray exposure age of 29 m.y. by the ^{38}Ar method.

Processing

A slab (,8) was cut from 14303 (figures 13 and 14) and most early allocations were from this slice. An additional slab was cut in 1986 (figures 3, 15 and 16). Carlson and Walton (1978) and Twedell et al. (1978) provide some details of 14303, but no guidebook was prepared and it is now difficult to identify additional materials from clasts that were extracted from this sample.


,15
,13
T3
,12
,14
T1
S1
E1
,32
,33
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,20
,12
,17
,19
,14
Note:
Numbers crossed out show
parent piece destroyed to
make two or more daughters,
otherwise, some of parent
remains.

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